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THE RELATION BETWEEN CERTAIN RIVER TERRACES AND THE GLACIAL SERIES IN NORTHWESTERN CALIFORNIA.

INTRODUCTION.

By a reconnaissance trip in February, 1903, the writer traced a definite system of river terraces between the coast at Humboldt Bay and the Summerville basin on the border of a high mountain cluster which was extensively glaciated in the Pleistocene period and still possesses three tiny glaciers. The importance of connecting the terrace system with the glacial series was recognized and the writer devoted some days to a detailed study of the extremely rocky and brushy canyon, seven miles in length, which separates the Summerville basin from undoubted deposits of the last great glacial stage. The work was greatly facilitated by the operations of the early placer miners, who have beautifully exposed most of the remnants of old channels. It is believed that this study was rewarded by exceptional success, of the truth of which the reader may judge by perusal of the following pages:

I have now discriminated in this region six distinct channel levels (including the present river bed) which, to facilitate the discussion, I will classify by letters, beginning with the highest. In my descriptions I distinguish constantly between "terrace" and "channel." Ordinarily each terrace consists of a rock bench with a flattened or channeled, water-worn surface (the channel level) overlaid by 5 to 20 feet of river gravel and this by a variable thickness of sandy clay and angular local rock débris, the surface of which constitutes the terrace level. Therefore, the height which I may give for a channel level is always less than that of the corresponding terrace level. Where mining has been carried on extensively, it is often difficult to determine the original surface level of the deposit, but where there has been no mining, the terrace level is the conspicuous feature. The channel is by far the most constant and safest guide to follow as the terrace level is locally raised by torrent fans from neighboring gulches.

The South Fork of Salmon River, in this region, has a nearly straight course (minor deflections excepted) from east to west, being controlled by the predominant joint system of the hornblende schist into which it has trenched a narrow valley, 3,500 feet in depth. It has migrated southward with the dip of the joints. In consequence, the channel remnants occur predominantly on the north side of the river. On the south of the river, back of the immediately overlooking peaks, there is a group of higher peaks, including Mt. Thompson (altitude 9,345 feet) and Mt. Courtney (altitude about 8,800 feet). Within the shadow of these peaks, there are a number of *cirques*, each of which, in the glacial period, was the gathering ground of an independent glacier.

CHANNEL REMNANTS FROM SUMMERVILLE TO BIG BEND BASIN.

The channel which comes up through the gorge below Summerville at a height of 30 to 50 feet, upon entering the Summerville basin seems to separate into two strands, of which the first becomes lower, relative to the river, partly because of partial filling of the channel by tailings, and spreads out to a bench, on the north side of the stream, several hundred feet wide (Channel E). Back of it, and apparently 15 or 20 feet higher, there is another broad shallow channel (Channel D). As we travel up through the basin, we find this latter occurring at 30 to 40 feet above the river, on both sides. The canyon in it is unusually wide and contains important remnants of the lower terrace. These two lower terraces have dark and light brown débris over the channel gravels proper, but no decided reddish tint. All higher terraces are characterized by a bright red color of the upper dirt layers.

Channel D seems to be the equivalent of the "lower terrace" or "broad valley floor," described elsewhere from the basins on the lower Klamath and lower Trinity rivers, and Channel E is a local development, scarcely occurring anywhere below Cecilville. Channel F is mostly buried under the gravel and bowlders of the present river bed.

At the upper end of the Summerville basin, at the mouth of Rush Creek, there is a very well defined terrace whose surface is at the outer edge about 100 feet above the river. It is well marked along the opposite side of the river as a rather sharp bench. On the north side, facing the river, it has been mined extensively, showing that under its sloping surface there are buried two distinct channels. The outer (Channel C) contained a very bowldery gravel bed from 20 to 30 feet deep, and the inner (Channel B) a similar but thinner and less coarse bed. Most of the bowlders are of the granite of the area on which it rests and from up Rush Creek. A few are of Courtney granite and there are rare small bowlders of serpentine, both from the main valley. The granite bowlders in places are thickly packed. Many are rotten to the center although three feet thick. The red stain in places extends from the surface to a depth of 20 feet. The deposit appears old. It rests on rotten granite. There is a fairly well defined granite platform about 75 feet above the river and a similar platform 30 to 40 feet higher. The sloping surface over these two channels is the main upper terrace of the Summerville basin, but seems to correspond to an intermediate terrace of the system studied nearer the coast.

Channel A is represented by a small river deposit occurring at about 250 feet above the river, just below the Summerville buildings. It is much older than any subsequent channel and the space between its level and that of the main upper terrace is characterized in many places by a peculiar rolling topography developed in rock. This high channel represents the floor of a comparatively broad valley, of which only a very few remnants remain. It dates back at least as far as the Red Bluff epoch. There are no traces of any higher river deposit in this region.

The valley carved below the main upper terrace at the mouth of Rush Creek may be 500 to 800 feet wide. In it are two main terraces, both well defined. The lower is 15 to 20 feet above the river level, and is trenched by the winding canyon of the present river, which is here several times as wide as the low-water stage of the stream because the soft granite erodes easily. The second terrace may be 50 feet above the river. These two lower terraces have fewer and less rotten large granite bowlders than those higher.

At Miller's suspension bridge the terraces, here well defined, are at about 20, 55 and 120 feet respectively. The rock is harder and the lower canyon getting smaller. The river next swings into the north bluff, cutting away the terrace system but leaving it well defined on the south side. The next swing is into the south bluff and cuts it out on that side.

From here to Big Bend Creek, the north side of the valley contained abundant remnants of the main upper terrace, which have nearly everywhere been mined off. The gravel layer was thin and contained few large bowlders. Over it there was, in the first remnants, 10 to 20 feet of indistinctly stratified local débris such as in the torrent fan at Cooper's mine (but less coarse) discussed in another paper[1] and the significance of which will come out later in this. In places it contains much clay and is red in color. The surface of this terrace sloped distinctly toward the river, but its rock bench, in so far as it constitutes Channel C is level. The latter is weli defined on four points and stands about 75 feet above the river. One can look across these points and see that there is absolute correspondence in height of the flat rock platforms.

The rocks are here hard hornblende schist and the canyon narrow from the upper terrace level down, but in it there are several beautiful remnants of the middle terrace (Channel D), half way down to the river. There is no room for the lower terrace. Above Channel C there seem to be several remnants of a level 30 or 40 feet above it (Channel B). Still higher there is a little channel about 30 feet wide, with a distinct outer rim of bed-rock, a few bowlders and a little gravel in the channel and this overlaid by about 20 feet of red, indistinctly stratified, rather subangular local débris. This may occur nearly 175 feet above the river and probably approximately represents Channel A. Far below it is the main upper terrace.

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[1] "Some Evidence of Two Glacial Stages in the Klamath Mountains in California," *American Geologist*, Vol. XXXI, March, 1903.

Just below Big Bend Creek, the covering of the regular river gravel in the main upper terrace by brown, not red, distinctly stratified and partly water-worn hornblende schist pebbles and subangular débris, as in Cooper's mine, becomes quite apparent. This is the downstream edge of the torrent fan of Crosby Creek, elsewhere discussed, and it is here 20 to 40 feet thick. It buries two channels. At 65 feet above the river we have the floor of Channel C, which from here upstream becomes the main or best developed upper channel. We know that it is Channel C because this is one of the four points just mentioned, and we can see that it absolutely corresponds to the channel which, farther down stream, stands at 75 feet above the river. The canyon is getting shallower. Channel D occurs on the opposite (south) side of the river at only 20 feet above the stream.

Channel C contains some large bowlders of Courtney granite and the regular river deposit is covered by about 40 feet of the Crosby Creek alluvium. Just back of it we have at 80 feet above the river, Channel B, which contains few large bowlders and is covered by a less thickness of the Crosby Creek alluvium. It is quite evident that the mass of local débris which came with a rush of water down Crosby Gulch and was distributed down the valley and stratified by the river, rests on nothing lower than Channel C of the Summerville basin. It is of the same age as the completion of this channel and it is the equivalent of the local débris which nearly everywhere seems to form the surface deposit of the main upper terrace of the Summerville basin and gives it its sloping surface. Its relation to Channel B is simply that there was such an abundance of material that it succeeded also in submerging the higher channel remnants.

At the mouths of Big Bend and Grizzly creeks, a belt of chlorite schist enabled the excavation of a basin about 1,000 feet square. The river makes a large bend around by the south, and descends rapidly, so that the terraces are higher above the stream on the downstream than the upstream side. In the east central portion of the basin there was a flat whose surface rose about 30 feet above the river on the upstream side, and whose bed-rock floor rises 10 to 15 feet above the same portion of the river. This is Channel D and the gravel was not covered by the local alluvium. On its downstream side there is a broad terrace rising 12 feet above the river. On the other side of the river there is a terrace whose bed-rock floor is 10 to 15 feet above the river and surface 20 to 25 feet above the stream. There is no local alluvium on it. It seems to be the last development upstream of Channel E. Back of it there is a marked remnant of a terrace whose bed-rock floor seems to be about 75 feet above the river. The surface is possibly 100 feet above the river. Within the canyon at the lower end of Big Bend basin, remnants of this channel occur on both sides of the river and lead directly to the last discussed development of Channel C. Similarly, the next lower channel occurs in the gorge as a long narrow bench on the north side, with rock floor 20 feet above the river.

At the mouth of Big Bend Creek there is an alluvial fan apparently made by that stream. It rests on the same bed-rock surface as the "15-foot channel" (Channel D) which is 25 feet above the river at the downstream end of the basin. The gravel is 65 feet thick and remarkable for the many large granite bowlders of Big Bend granite, some of which are so large that it seems incredible that the Big Bend Creek could have carried them. The surface is rough and bowldery, and sloped distinctly toward the river. Some features indicate a glacial origin but the deposit seems waterlaid. The age is the same as that of the gravel of Channel D.

FROM BIG BEND BASIN TO COOPER'S MINE.

Between the Big Bend and Little South Fork creeks, there are several marked remnants of the main channel (Channel C), crossing points on the inner side of curves in a new course of the river. The local alluvium which was deeply piled over the regular river deposit, displaced the river repeatedly and compelled it to take a somewhat serpentine course. Consequently the new canyon is not everywhere directly under the old.

At the upper end of Big Bend basin, Channel C has a height above the river of only 50 feet, but is clearly seen to be the same level as the 75-foot channel at the lower end of the basin. Small remnants of this 50-foot channel occur on each rock point on the south side of the river for some distance upstream. Below them there is a long narrow bench of the 15-foot channel (Channel D). On the first prominent point on the north side, the main channel is 50 feet above the river, but at 70 feet there is another channel (Channel B). Both of them were buried under the stratified local débris, the lower the deeper. On the same point occurs a marked remnant of the 15-foot channel, which was not buried under local débris.

The next point on the south of the river has a marked remnant of the main old channel whose floor is here 55 feet above the river. There is a distinct outer rim. The new canyon is 75 feet (minimum) in depth. Over the old channel gravel there is at least 40 feet of local stratified alluvial débris (including that of the Crosby Creek fan). There is also a remnant of the higher channel.

The next point on the north side of the river has a narrow remnant of the old channel system. It is about 50 feet above the river and is distinctly higher than the main channel remnants on the south points both above and below this point. Hence it represents Channel B. There is not much local débris left over it.

The next point on the south side of the river, which is a short distance below Little South Fork Creek, has an important remnant of Channel C. Its rock floor is 75 feet above the river, it has a distinct outer rim, and the new channel has been cut into solid rock 100 feet deep as a minimum. Over the gravel there was stratified local débris 30 to 40 feet thick.

The slight variation in height above the river, of the different remnants of a given channel is due to the facts that the river always has had a variable grade because of harder and softer rock belts and that the present higher grade and lower grade sections do not quite correspond with those of the past. As a matter of fact, the older channels were better graded than is the present river bed.

In ascending the river from Summerville, Channel C gradually approaches the present river level and the new canyon, at first thought, might appear to be smaller. In reality, I have found, to my surprise, that the river everywhere has accomplished about the same amount of cutting in rock of a given hardness. The new canyon above Big Bend basin is largely excavated to one or the other side of the old course and includes the removal of considerable rock above the level of Channel C.

Along the old Spooner ditch on the north side of the valley, overlooking the old channel remnant just described, there is an area of gravel about 1500 feet in length and 100 to 200 feet in width. Its lower edge seems to be about 300 feet above the river, and it ranges to at least 100 feet higher. Near the western end it seems to rest on a bed-rock slope of 10° to 20°, much less than the slope above or below. The ditch is cut into it for several hundred yards to a depth of about 10 feet and splendidly exposes its interior. It is a heterogeneous agglomeration of bowlders and pebbles and subangular rock fragments embedded in a grayish (partly brown stained) sandy clay. There is no sorting of the material and not a trace of stratification. Its general appearance is that of a glacial deposit, but it is so old and rotten that if any striae existed they have been destroyed by decay.

The larger bowlders are chiefly of hornblende schist from the subjacent terrane, Courtney granite from near the head of the river and massive serpentine. The latter are plentiful enough to be conspicuous. Bowlders 18 inches to 2 feet in diameter are found without much difficulty. The largest bowlder observed is a serpentine 4 × 4 × 5 feet. The remarkable feature of this serpentine constituent is that serpentine does not occur in place anywhere in the basin of the *old* Salmon River between this point and its head. The evident source of these bowlders is a serpentine area on the eastern side of the *old* Coffee Creek valley, within several miles of its head. That portion of the *old* Coffee Creek valley has been captured and is now drained by Salmon River. A study of the gorge at the head of the *old* Salmon River valley indicates that the beheading occurred late in the glacial period, that is, was associated with one of the later glacial stages as will appear later in this paper. Salmon River now has access to the serpentine and is bringing a small percentage of serpentine pebbles and cobbles below the gorge, but they are soon worn out so that at the distance of three miles from the gorge they are extremely rare in the present river deposit. One so rarely finds a specimen of them in the old channels up to this deposit under discussion, that they may be considered practically absent. Why are they so characteristically abundant in this higher and older gravel? I have but one plausible explanation of it. A glacier headed in the *old* Coffee Creek valley, overrode the col at the head of this valley and sent a shallow tongue far beyond any point reached by subsequent glaciations—three miles farther down the valley than the distinct glacial moraines to be described later, and to a locality now but 3,700 feet above the sea.

Whether this is a glacial or a river deposit, I am going to refer its level to Channel A. I am going to show traces of the same deposit for several miles up the valley at nearly a uniform level. They seem to have been deposited on the valley floor where it joined the steeper mountain slope. Therefore, I consider them to represent the level of the valley floor of that time in much the same way as do the old channel deposits.

In this deposit along the Spooner ditch all the granite bowlders are thoroughly rotted to the core. So they are in certain portions of the lower channels. But here other rock species which are not usually much decayed in the river channels, fall to dust. Various porphyries, diorites, gabbros, and schists will not bear handling. The serpentine bowlders are hard, but pitted and honey-combed. Even the hornblende schist, which is one of our most resistant rocks, has an aged and incipiently decayed appearance.

The local material is mostly somewhat angular, but the foreign material is better rounded. Some pebbles undoubtedly show river action, but more convey impressions of the faceting characteristic of glaciation. An otherwise angular hornblende schist fragment a foot in length has been worn smooth and flat on one side and there are the faintest traces of striation.

The unique character of this deposit is generally recognized by the people who refer to it as a "glacier wash." Prospectors say that it contains a little fine gold uniformly distributed through it, and not concentrated into a basal stratum as in an old river channel. The bed-rock surface is somewhat uneven, but is decayed and, besides, not well exposed. Following the deposit toward the east the bed-rock surface on which it rests very quickly gets to 50 feet above the ditch, and the serpentine-bearing débris ranges to over 100 feet higher. This is quite unlike the habit of an old channel remnant.

There is a 12-inch serpentine bowlder and some rounded cobbles, associated with red dirt, along the old Spooner ditch above the mouth of the Little South Fork Creek. About one-fourth of a mile farther up stream there is a 12×18-inch serpentine bowlder in a draw on a very rocky and steep slope just below the old Spooner flume and probably 200 feet above the river. There are no other erratics and this has evidently slidden from higher on the hill-side.

From the mouth of the Little South Fork Creek to a little point just below the Deep Bank mine, the new course of the river approximately coincides with the old, and all the old channel gravels and local alluvium have been swept from the canyon. The canyon is very narrow and extremely rocky, there being at places, particularly on the south side, perpendicular rock bluffs 75 to 100 feet high. Probably the new canyon has been cut down from 50 to 75 feet below the floor of Channel C, but in addition there have been considerable slices of rock taken off from the walls of the old canyon, so that the steep rocky walls of a modern appearance rise to 200 and 300 feet above the river. This canyon is so narrow, crooked, and rough-walled, and there are so many projecting narrow rock points, that it is unreasonable to suppose that it has ever been glaciated. If the serpentine-bearing horizon which occurs above this canyon is truly referable to glacial action, the valley has been cut down into very resistant hornblende schist to a depth of at least 200 feet and probably nearly 300 feet since the glaciation. Channel C is far below and very much newer than these supposed old glacial deposits.

The School-house Flat, opposite the mouth of the Little South Fork Creek, probably 500 or 600 feet above the river, has dimensions about 400 × 500 feet, seems to be composed of broken hornblende schist, shows slight landslide topography, no gravel and is very steep on the side toward the river, so that it resembles an old river terrace remnant. A considerable area for some distance west of this flat shows typical landslide topography. Farther up the valley there is another terrace-like landslide deposit, occurring probably 600 feet above the river and occupied by Lakeview, a small ranch.

At the lower end of the Deep Bank deposit the bottom of Channel C is 45 feet above the river. Just across the river on a small point there is a fragment of the same channel and below it a newer channel (Channel D) with its rock floor 15 feet above the river. The outer edge of the Deep Bank is about 200 feet above the river and the inner edge about 250 feet. Just west of the Deep Bank, resting on a steep slope at about the level of the inner edge of the Deep Bank, there is a large granite bowlder (Channel A). The face of the Deep Bank displays stratified, coarse, subangular dark brown (reddish in layers) Crosby Creek alluvium about 100 feet thick. In the channel deposit there are many granite bowlders, rotten but with a hard core. The rock cutting of the new canyon is from 100 to 150 feet in depth, the latter on the south side.

The first south point above the Deep Bank has a marked rock bench at 15 feet above the river (Channel D, occurring in the new canyon) and back of it a remnant of Channel C. Immediately opposite is the lower end of the most important remnant of this old channel, that opened as Cooper's mine, discussed in the paper before cited. It is preserved for several hundred yards, the river occupying a rock canyon on the south of it. At the lower end the deep narrow channel has its floor about 40 feet above the river. On the borders of the deep channel are flattish, water-worn rock benches which probably represent Channel B. Thin remnants of the ordinary river deposit occur in the bottom of the deep channel. The pebbles are well rounded and the granite bowlders comparatively small. Over this occurs 40 to 50 feet of a stratified deposit partly of subangular local débris, but abounding in granite bowlders, many of large size. This is not the regular river deposit, thins rapidly down stream, becomes very bulky from here up, and I consider it the combined Crosby Creek alluvium and the overwash gravel and bowlders of a glacier which terminated over a mile up the river. Over it is the stratified angular local débris of the Crosby Creek torrent fan, extending to the brow of the hill, nearly 300 feet above the river. Granite bowlders derived from up the river are sparingly scattered through it.

A ditch in the slope of the mountain just above the inner edge of this alluvial fan, exposes a small area (póssibly twenty yards in diameter) of rotten granite bowlders and local débris embedded in a sandy clay. It seems to pass down under the edge of the torrent fan and is certainly older. It seems to represent Channel A, having the proper height (350 feet above the river), the aged appearance and the apparent glacial characteristics. On the same line west, but in Crosby Gulch, a large rotten granite boulder is buried under the stratified alluvium of the Crosby Creek fan.

NEAR AND IN THE GLACIAL AREA PROPER.

At the upper end of Cooper's mine a depression crossing a rock point seems to represent the deep channel naturally mined off by the river. Its floor is 45 feet above the stream. Directly opposite the present river but in line with the old channel below, the bowlder bed which is so characteristic in Cooper's mine passes into the bank, has been mined somewhat and the rock floor shown to be a stream channel. But this rock floor is 100 feet above the river. The old channel may have descended very rapidly at this point, although it is more likely that it is one of the higher channel surfaces in Cooper's mine that is represented, and that the deep channel passed up through the gorge.

The channel on the south of the gorge is preserved for about 500 feet, and is covered by a mass of angular local débris whose surface forms a sloping terrace with outer edge several hundred feet above the river. From where this channel issues from the bank, for fully half a mile up the river, the old and new courses are coincident. But the level of the old channel floor is marked by a change from the precipitous canyon wall to a gentler and less rockier slope above, with an occasional granite bowlder at this level.

On the north side of the river, about one-fourth mile from the lower end of Cooper's flume, there is a cutting through a narrow point, on which occurs a remnant of gravel about 30 × 100 feet in extent and 5 to 20 feet deep. It rests on a rock slope of about 45° and ranges from the level of the flume, about 300 feet above the river, to 75 feet higher. The bed-rock surface under the gravel is broken and decayed and somewhat irregular. It does not seem to be in the form of a distinct channel. The material abounds in large granite bowlders which are thoroughly rotten to the core, even one 6 × 8 feet. The remainder of the rock fragments are mainly angular and sub-angular hornblende schist up to bowlder size. Aside from the granite bowlders, very little of the material is rounded. It is embedded in a sandy clay, inclined to a reddish color. There are no apparent lines of stratification. It looks more like a glacial than a stream deposit. It is very old and rotten and a mere remnant of a once more extensive formation. The lowest portion is over 150 feet above the floor of Cooper's channel, the surface of which, as already described, forms a terrace on the opposite side of the river. This gravel contains an 8-inch and a 2-foot serpentine bowlder, and represents the serpentine-bearing horizon, down the river.

Higher on the same slope, by the "Cape Horn" trail, about

600 feet above the river, there are the huge fragments of a single granite bowlder which had dimensions about 15 × 20 × 30 feet, about 700 tons in weight. There is no gravel with them. They rest on the sloping surface of the hornblende schist and apparently were higher but have slipped down. The configuration of the country is not now, and never has been, such that this bowlder of Courtney granite could have rolled down from its original position on the high mountain to the south. Further, Salmon river never was large enough to have transported this huge bowlder by any process speedy enough to have avoided wearing it out. Bowlders nearly as large are now lying in the bed of the river, but I have recently discovered that they rode into the valley on the backs of glaciers, and the river has not been able to move any of them far down stream. This bowlder apparently reached about its present position by glacial action, and I am compelled to refer it to the supposed glaciation represented by the "Channel A deposits." A flat-lying remnant of them occurs 30 feet above Cooper's flume at "Cape Horn."

At the upper end of the gorge (at the head of Cooper's flume, one and one-eighth miles up stream from Cooper's mine) we have the floor of Cooper's channel (Channel C) well marked as a bench on the south of the canyon, lying 75 to 100 feet above the river. It is encumbered with huge granite bowlders, not much decayed. Turning down stream from the head of the flume, the channel bench occurs on a point overlooking the deep, narrow canyon. Immediately back of it and advancing a point completely across it to the edge of the canyon, there is a pile of rock débris rising in a steep slope to over 100 feet above the old channel and then going back several hundred feet with a gently rising but undulating surface. It abounds in large granite bowlders, some of which occur on its surface. The flattened, plateau-like surface sends a narrow ridge northwestward to the edge of the canyon. On its southwest side there is a gently descending, broad, shallow, rounded depression, clearly not the result of erosion, but such a depression as commonly is found outside of glacial moraines. Back of this depression there is a long, smooth, gentle slope (without granite bowlders) gradually changing into the steep slope of the mountain above. The bowldery ridge is a glacial moraine. Its steep inner slope is largely due to erosion by the river. It obstructed the old channel and caused the erosion of the canyon.

The surface of the bowlder deposit rises toward the southeast at the rate of 10 to 20 feet in 100 feet, and soon attains a height of over 500 feet above the river. It has, at first sight, the appearance of a typical lateral moraine, with steep inward (ice-ward) slope, then a flat surface 30 to 150 feet wide and then the smooth slope of the unglaciated mountain. This moraine leads to the mouth of a deep gulch (Brown's Gulch) which comes down steeply from the mountain on the south and enters the river valley not far above the head of Cooper's flume. A glacier headed in a basin in the granite at the head of the gulch, extended down the steep, narrow gulch and out into the valley of the Salmon River. This may be called the Brown's Gulch glacier.

The moraine surface at the mouth of the mountain gulch is about 200 feet above the creek. The gulch is so sharply V-shaped as to indicate considerable postglacial erosion. From here up the bowlders on the west are simply scattered over the slope of the mountain, bed-rock appearing frequently, and in many places there is little to indicate a glaciated gulch.

The corresponding "lateral" moraine on the east side attains prominence farther up the gulch and quite likely extends without a break to the glacial basin at the head. The appearance is that this supposed lateral moraine really represents the floor of the glacier and that of the stream has cut a V-shaped gulch 150 to 200 feet deep and partly in hard rock, since the disappearance of the ice. This is an amount of erosion that I am not accustomed to for the time since the maximum extent of the Wisconsin glaciers.

Following the east moraine down, I find it finally separating from the general mountain slope as a broad, transversely flat-topped, independent ridge. This gradually diverges from the west moraine, showing that the glacier, upon entering the main valley, spread out like a fan.

The ridge ends abruptly on the edge of the main valley at a height perhaps 300 feet above the river. A small ditch passes around the point not far below the brow of the hill and its bank exposes the glacial débris. Proceeding east along the ditch, one comes to a fresh ravine leading down the steep slope from the ditch. It exposes 100 feet in thickness of horizontally-stratified, fine, subangular, brown gravel and reddish-brown silt, like in the high bank above Conzetti's mine, discussed in the paper before cited; but here containing a number of granite bowlders, all rotten even when 3 feet in diameter. It is evident that this glacier dammed the valley and formed a pond 300 feet deep, in which the fine gravel and silt accumulated, but right here along the edge of the moraine, granite erratics slid from the glacier into the pond.

Two hundred feet farther east along the ditch we seem to be completely beyond the limit of the glaciation as the bank thence for a long distance shows only residuary débris.

Remnants of the terminal moraine occur on the north side of the valley, opposite the ends of the lateral moraines and connecting these two points, a distance of about 500 feet. Scattered bowlders reach a height of several hundred feet, but hardly high enough to explain the damming of the valley above and formation of the stratified gravel and silt by the moraines alone. Apparently the silt and gravel reached their upper levels by actual ice-damming.

Returning now, to the head of Cooper's flume, we will take up Cooper's channel, here marked by a rock bench 70 feet above the river, and trace it up stream. By reason of the high grade of the present river, the old channel reaches the stream level about 400 feet up stream, and the present rock canyon ends at that point. From here up the valley is comparatively broad, is encumbered by huge bowlders (the residua of the eroded glacial deposits) and no bed-rock shows in the south bank for some distance. From here up the old channel is buried under the present river-bed and passes out of the discussion.

The connection of Channel C with the maximum extension of the Brown's Gulch glacier seems sufficiently definite. This glacier built its moraines directly across the old channel, compelling the river to adopt a more northerly course and erode a new canyon. The overwash gravel and bowlders from the glacier were distributed down Channel C to a point below Cooper's mine. Before this was completed a cloud-burst in the basin of Crosby Creek, formed the torrent fan which is so certainly traceable down the main valley nearly to Summerville. The building of local débris fans over Channel C was an especially characteristic feature everywhere and we are now able to connect it with the glacial stage represented by the maximum extension of the Brown's Gulch glacier. I accept this as evidence of an abnormally moist climate and heavy precipitation in the territory outside of that involved by glaciation.

We will now transfer our attention to the vicinity of the upper falls of the Salmon River, in the gorge which marks the original head of the *old* Salmon valley. Above the gorge, the flat floor of hornblende schist extends out into the broad valley 100 yards as exposed by the river. Since the last or Wisconsin glaciation, the river has carved in this rock platform a canyon 30 to 50 feet deep, and 30 to 50 feet wide at the bottom, with steep, in places, precipitous slopes Through the upward rise of this rock platform and the high grade of the stream, the canyon has become probably 75 feet deep at the upper end of the gorge. A sort of terrace is traceable from the edge of the glaciated platform down through the gorge, particularly on the south side. Next to the river there is a precipitous rock slope capped by granite bowlders. Back of this there is a comparatively gentle slope, encumbered by huge granite bowlders. Above this there is a very steep, rugged slope, apparently unglaciated. The summit of the ridge is rounded, smoothed and covered with erratics. The Salmon River glacier in the last stage clearly overrode this ridge, and seemingly spanned across the gorge to the ridge on the north, whose summit it rounded and covered with glacial débris. The slopes within the gorge are apparently unglaciated (so far as the last stage is concerned) as ragged rock surfaces abound. But the bottom of the gorge at that time was a U-shaped valley descending as rapidly as the present river; certainly it was not such a narrow, rocky canyon as the present bottom of the gorge. Possibly a small glacial tongue extended down this valley at times, but the bowlders on the south terrace are so numerous and are piled up above the soil in a way to indicate that they were carried over the crest of the ridge on the south and rolled down to the bottom of the valley. Since this event, Salmon River has cut a rock gorge under the older valley, 50 to 75 feet deep. *It descends several hundred feet in less than a quarter of a mile.*

This canyon I attribute to late Wisconsin and post-Winconsin stream erosion. It is rather larger than I am accustomed to for the product of that time, but the flat platform above the gorge, in which this canyon is partly excavated, certainly was glaciated during the last or Wisconsin stage. This canyon is proportionally somewhat smaller than that eroded since the abandonment of Channel C down the river, but at first thought there does not seem to be any very great contrast between them. However, on the ground, the impression is very quickly made on the observer's mind that this upper canyon is much newer than that down the river which succeeded Channel C. Conditions for erosion are exceptionally favorable because it is very high grade. The river descends through it in a series of falls, with perpendicular drops at two places of over 20 feet. The rock is not exceptionally resistant. If this same river had flowed through this gorge since the abandonment of Channel C, it could not have failed to have cut back to the center of the broad valley above instead of only cutting a notch in the edge of the broad, inward-sloping valley rock-floor.

Tongues of ice from the main Salmon River glacier undoubtedly overrode the col during the earlier glacier stages, but during the interglacial or minimum stages, Salmon River did not flow through the gorge, as otherwise it would have completely destroyed the very high grade character of this short section of its course. The broad valley above the gorge was drained by Coffee Creek until late in the Wisconsin or last glacial stage as is evidenced by a broad valley eroded in the earlier glacial deposits just outside of the terminal moraine of the Salmon River glacier in its last stage. This terminal moraine is trenched by an insignificant notch, too small for such a stream as Salmon River to have flowed through it for a single week. When the glacier front fell back a mile, it formed another moraine which dammed the broad valley and turned the drainage of the upper valley through the gorge into the *old* Salmon valley. Therefore, I place the inception of cutting of the canyon in the gorge at a time very little later than the maximum extension of the glaciers of the Wisconsin stage and consider this canyon not more than one-third as old as that eroded since the maximum extension of the Brown's Gulch glacier.

Following the bowlder slope on the south side of the gorge down the valley, its edge gradually gets higher above the river. The bowlder strip becomes pretty steep, then rather suddenly changes to a flat terrace, 150 feet above the river, and whose surface has granite erratics about as numerous as on the floors of most glaciated valleys. This apparently represents the floor of a glacier and we have passed beyond the bowlders which have rolled down from the mountain. The steep slope facing the river is due to stream erosion. Half way to the river is a remnant of another flat terrace, also encumbered with bowlders.

Very shortly the glacial terrace gives out and we come to a slightly higher and steeper slope which has no granite bowlders and seems to be composed superficially of local débris. This is bounded on the river-ward side by a steep bluff 200 or more feet high. On this slope occur granite bowlders. The phenomena indicate a glacial deposit upon which has been built up an alluvial cone of local débris. The river flows in a rather broad canyon trenched below this level.

This slope has an angle of about 15°. Its width from the upper to the lower edge is about 400 yards. Following it down the valley we find built on it a bowldery terminal moraine of the Cohnrad Gulch glacier, which came down from a *cirque* on the northern face of Mt. Courtney. Between this moraine and the river the long slope descends to within 100 feet of the stream, acquires granite bowlders, then becomes undulating and very bowldery, and forms a distinct moraine which appears on both sides of the river and has been cut through by a gorge probably

50 feet deep. Thence extending a quarter of a mile down stream, we find a strong moraine development, great piles of huge granite bowlders rising from along the river to the foot of the steep mountains, a quarter mile back from the stream. This was evidently the work of the Cohnrad Gulch glacier, which barely reached the north side of the valley and scarcely dammed the river. It is a strand of this moraine system that rests on the between 100 and 150 feet of stratified fine gravel and silt above the Conzetti mine, as discussed in the paper before cited. From the way the same moraine system comes down near the river one-fourth of a mile farther up, there was apparently much erosion between the deposition of the gravel and the glaciation of its surface. This is a different conclusion than I have heretofore expressed, as I maintained, in the paper referred to above, that there was no dissection of the fine gravel deposit before the formation of the overlying glacial moraine, but it now appears that that statement was too hastily made. It now appears that a deep, comparatively broad canyon was excavated by the river into this gravel deposit, and subsequently when the Cohnrad Gulch glacier reached the edge of this canyon it tumbled much of its moraine material into it. The maximum extension of this glacier certainly occurred later than the maximum extension of the neighboring Brown's Gulch glacier, and there is evidence of such a long interval between them as constrains me to refer the former to the Wisconsin or last great stage of glaciation. This conclusion is supported by Cariboo Creek having excavated in this glacial débris a much smaller trench than Brown's Creek eroded in solid rock since the maximum extension of the Brown's gulch glacier. Why these two neighboring glaciers should have see-sawed in this manner is not clear, but from a neighboring mountain I have seen that they headed in adjoining *cirques* which seem to have been fed jointly by a higher *cirque*, and a careful examination of the locality may furnish a satisfactory explanation.

Under the stratified gravel and silt just mentioned there is a thin layer of fine gravelly blue clay, which rests on a bed of coarse bowlders and ordinary river gravel. The blue gravelly clay is very strongly contrasted with both the underlying and overlying deposits. A little farther west it is exposed along the bank for several hundred feet and has a thickness of 6 to 8 feet, with the bottom not seen. It is partially indurated so as to resist erosion well. It is without any apparent stratification and its general appearance is that typical of the ground moraine of a glacier. The included pebbles are partly subangular and partly well rounded. There are faint traces of striation. No serpentine is present, consequently the deposit must be referred to an early stage of the Cohnrad Gulch glacier, a stage apparently closely preceding the maximum extension of the Brown's Gulch glacier and certainly long preceding the stage which formed the moraine *over* the stratified fine gravel and silt.

We will return our attention again to the vicinity of the gorge at the head of the *old* Salmon valley. At Cooper's saw-mill, which is just below the gorge, there is the first of a series of remnants of a terrace which extends down the valley, with a level at first about 50 feet above the river, but gradually decreasing to 30 feet. It is, at the saw-mill, a rock bench covered with gravel and bowlders. The canyon trenched below it is comparable with that developed in the rock platform above the gorge, and I consider this level to represent the closing stages of glaciation in the broad valley above the gorge. The rock bench rapidly descends below the river level and thence the terrace remnants appear to be built entirely, displaying nothing but gravel and bowlders in the bank. This deposit partially filled a rather wide trench excavated by the river into the earlier glacial deposits and the lake deposit of fine gravel and sand. In the vicinity of Conzetti's mine there are several flat-topped remnants of this terrace which lie 30 feet above the river and which formed part of the valley floor at a time long succeeding the Brown's Gulch maximum glaciation; Conzetti is probably in part working this deposit in his hydraulic mine. Unfortunately, between here and the lower old channel remnants farther down the river, there are no more remnants of this late Wisconsin terrace; but it is safe to say that it is not older than Channel D and not newer than Channel E.

On the northern side of the valley, above the saw-mill just mentioned and hence just below the gorge, glacial débris is scattered thinly over the slope to the summit of the ridge, fully 700 feet above the river and 250 feet above the Big Flat on the opposite side of the ridge. There are some large granite bowlders, but among the material of lesser size, serpentine is conspicuously abundant. This I suppose to represent the last or Wisconsin glacial stage, the material seemingly having fallen from the ice spanning across the gorge. Serpentine occurs in equal abundance in the Wisconsin drift in the broad valley above the gorge. The serpentine is only proportionally abundant among the finer material. Small bowlders and cobbles well-smoothed represent the subglacial and the lower stratum of the englacial drift. Among the large angular and subangular bowlders which were superglacially carried, serpentine is rare in the Wisconsin drift near the gorge, a fact which must be taken into account in comparing this with the serpentine-bearing apparent drift farther down Salmon River.

Leading down the river for about a mile and a half from the saw-mill, the north side of the valley has a more or less continuous strip of glacial moraine material which shows a tendency to form an imperfect terrace at a level between 100 and 200 feet above the river, with a few scattered erratics higher on the mountain slope. This terrace corresponds to that which we have traced on the opposite side of the river. The depression between seems to be a valley of erosion, several hundred feet wide and containing the lower terrace which I have referred to the last glacial stage. If this interpretation be correct, a longer time of erosion separated the two glacial maxima stages than has succeeded the close of the last.

The glacial material forming the indistinct upper terrace on the north of the valley, contains an occasional serpentine bowlder, proving that it was formed by a glacier coming from beyond the gorge, but so far I have failed to find within it serpentine in nearly the abundance in which it occurs on the higher slope just west of the gorge and in the supposed old glacial deposit along the Spooner ditch. I am constrained to consider it as representing neither the earliest nor the latest glacial stage yet recognized here, but an intermediate stage, probably equivalent to the maximum extension of the Brown's Gulch glacier.

GENERAL CONCLUSIONS.

The preceding detailed descriptions seem to have pretty definitely developed the following:

1. That there was apparently a very old glaciation which connects chronologically with the highest series of river terraces developed in the Pleistocene valleys between Summerville and the coast.

2. That there was an intermediate stage of glaciation which connects definitely with one of the intermediate terraces down the river.

3. That there was a last great glacial stage which connects indefinitely with the lowest series of river terraces, including the "flat valley floor" of the basins between Summerville and the coast.

The relation between the glacial deposits and the river terraces is of extreme importance because a knowledge of it enables us to roughly determine the relative ages of the different glacial stages by erosion studies in a region without the glaciated area and where conditions were more uniform. In this manner I derive the following ideas:

1. That the intermediate glacial stage (always referring to the maximum extension of the ice in each glacial stage) was about three times as long ago as the last glacial stage.

2. That the earliest apparent glacial stage occurred at least ten times and perhaps twenty-five times as long ago as the last stage.

Now, in personally inspecting the various drift sheets in the Mississippi basin and in comparing my observations with those of others, I have acquired the idea that the Iowan drift is from three to five times as old as the Wisconsin, the Illinoian ten or fifteen times as old as the Wisconsin, and the Kansan at least fifty times as old as the Wisconsin. Hence, there naturally follow, as final conclusions:

1. That the deposits of the last great glacial stage in the Klamath mountains fully represent the Wisconsin glaciation.

2. That the intermediate glacial stage probably corresponds to the Iowan.

3. That the deposits supposed to represent the earliest glacial stage yet recognized are *at least* as old as the Illinoian and perhaps as old as the Kansan glaciation.

CLIMATIC CONDITIONS DURING THE SEVERAL GLACIAL STAGES.

The comparative abundance of serpentine in the earliest supposed drift of the Salmon River valley and its rarity as superglacial material in later drifts raises a question as to the cause of this difference. A given glacier in each stage occupied the same valley and would be expected to yield drift of like constitution.

Linked with this phenomenon there is another. I know that the earlier glaciers ran farther than the later, and I have acquired the idea that they were of a radically different character, particularly that they were much thinner at a given distance from the end than were the glaciers of the last stage. This may be wholly imaginary, but I usually do not acquire such ideas without there being some basis for them; in the field I have now studied the earlier drift in three distinct areas (the Union Creek, Coffee Creek, and Salmon River valleys) and each independently has made a similar impression on me. This is after eliminating all differences due to the profound erosion of the earlier drift.

The only satisfactory explanation of the phenomena that has come to light is that as between the earlier and later glacial stages there was a radical difference in the *character* of the climate. *The earlier drift was formed under low altitude conditions and the later drift under high altitude conditions.*

On a recent trip from the coast at Eureka to this region, made shortly after a severe snow-storm, I had the opportunity of observing some meteorological phenomena having a direct bearing on the question at issue. On Redwood Mountain near the coast I found at an altitude of 3,600 feet, a depth of six feet of snow. As I advanced inland, the line of, say, two feet depth of snow gradually rose, and when I reached the region under discussion, I found that there had been not more than two and a half feet of snow at an altitude of 4,300 feet. A yet greater difference was observed in the melting of the snow. Near the coast the atmosphere was uniformly cold and dense, the sun's direct rays had comparatively little power, and there was no very great difference in the rate of melting of the snow on opposite sides of the valleys. Farther inland and at a higher altitude, the atmosphere was clearer and lighter, weakly absorbent of the sun's rays and radiation rapid. The result was a great contrast in the rate of melting of the snow on opposite sides of east-west valleys. It is well known that it is the great characteristic of an alpine climate that the general temperature of the air is low, but that the sun's rays by direct impact on the earth are very powerful. There is, therefore, a great contrast between the heat in light and shadow, a contrast which is much less at lower altitudes. At this camp, the southern side of the valley will be covered with snow down to the river level, while the sunny slope will be completely bare to an altitude 2,500 feet higher. A northerly facing gulch will be impassable from snow a month after flowers have been in full bloom in a southerly facing gulch at the same altitude.

In my first paper on the ancient glaciers of this region I called attention to the fact that in the last stage (the only one there discussed) they were apparently very sensitive to light and shadow, in their retreat creeping up close to precipitous peaks. It has long been evident to me that the Salmon River glacier in its last great stage was much higher on the west than on the east side, because its chief gathering ground was in the shadow of a high spur of Mt. Courtney, where there is even now a small glacier. Blocks of granite fell from the saw-like crest of the mountain and traveled across the surface of the glacier so as to be distributed along the east slope of the valley. Under these conditions serpentine from the east side of the valley could not very well superglacially reach the gorge on the west side and be carried down the *old* Salmon River valley.

Under low altitude conditions, this glacier would not have been so sensitive to sunlight and one side would not have greatly predominated over the other. Indeed, it is probable that in that case the longest feeders would have come from the heart of the serpentine area on the east and the conditions for the distribution of the serpentine would have been at least equally as favorable as for the granite. The serpentine-bearing drift appears to me to be more nearly normal than the other. It is fair to acknowledge that the earliest glaciation undoubtedly incorporated in its drift preglacial river deposits in which serpentine occurred in proportion to its outcrop area but this does not fully explain the contrast. It was the peculiar or abnormal character of the later glaciers which caused granite erratics to be present in the drift in a proportion entirely in excess of the outcrop area that caused the difference.

Further, the more uniform temperature of a low altitude climate would enable the early glaciers to run farther down the valleys even though thinner at a given distance from the end than the later glaciers and perhaps containing no more ice. Earlier glaciation was less vigorous than later glaciation. Probably the climate was colder at a given altitude than during the last glacial stage and the ice was sluggish. There seems to have been less tendency for the formation of large moraines than later.

At about the time of the last glacial stage, the country was uplifted and brought under high altitude conditions. The glaciers formed rapidly in the shadow of the peaks, but when they ran out into the open, into strong sunlight, they were soon pinched off by melting.

The character of the climate during the last glacial stage was similar to the present, except for a general lower temperature. Therefore, the altitude may have been at least as high as the present. The character of the climate during an early glacial stage seems to have been similar to that which now belongs to a lower altitude than the present, except for a general lower temperature. These mountains might have been, in an early glacial stage, 3,000 feet lower than at present, but not more, as a depression to that amount would nearly submerge the Summerville basin. Glaciation occurring at such an altitude would, judging from observations made near the coast, yield products similar to the earlier drift discussed in this paper.

In studying the river terraces between the coast and the Summerville basin, I independently arrived at the conclusion that the region of glaciation rose at least 2,000 feet and perhaps nearly 3,000 feet relative to the coast line, at approximately the time of the last great glacial stage and that this region is now as high as it has been at any time during the Quaternary era. Thus two distinct lines of argument are mutually corroborative and virtually establish, to my satisfaction, the fact of such an uplift. It is practically certain that the early glaciation of this region occurred under a lower altitude than the present. Therefore, the theory of elevation as directly and solely the cause of glaciation is inadequate.

I will suggest that there is between the earlier and later drifts in the Mississippi basin a contrast of practically the same character as I have imagined to exist here and perhaps the same explanation may apply. It is well known that there are in connection with the Wisconsin drift sheet evidences of greater elevation during that epoch than during preceding glaciations. During the Kansan, Illinoian and Iowan stages, the altitude may have been low, the climate very cold and comparatively uniform over broad areas, the ice-fields sluggish and the moraines formed, weak. The cause of the glaciation, as many now think, may have been something quite independent of elevation. During the Wisconsin stage, differential elevation may have temporarily resuscitated the ice-fields, but it also brought them under the influence of higher altitude climatic conditions, they were vigorous, but melted rapidly along the borders, ended abruptly and formed massive moraines.

As to the prime cause of the past glaciations, I am as yet far from convinced. At present I am most strongly inclined toward the atmosphere–composition–variation theory as defined by Chamberlin, but some of the ideas advanced in this paper hardly support it. My attention has been called to the fact that what I have described as the great characteristic of the glaciers of this region in their last stage, namely, their sensitiveness to sunlight, may have been produced at a lower altitude than the present, by a decrease in the carbon dioxide in the atmosphere, which is true. At the same time, the theory seems to imply that to bring about glaciation it was necessary to produce in the atmosphere at the altitude at which glaciation occurred, a depletion in carbon dioxide to considerably less than the present. This would intensify and bring down to a lower altitude than at present what I conceive as the characteristic of a high altitude climate. The earlier glaciation in this region, it would seem to imply, was produced under climatic conditions similar to those which obtained in the region of the later glaciation, although in the former case the altitude was apparently 3,000 feet less. This is contrary to the testimony of the field evidence, if I have read it aright. Perhaps my meaning will be clearer if I state that I conceive that the earlier glaciations occurred in an atmosphere having a larger percentage of carbon dioxide and watery vapor than is now present in the air of this locality.

I expect the reader to accept my argument as to the essential difference of the climate during the earlier and later stages of glaciation of these mountains as suggestions rather than as settled convictions even in my own mind. The study is yet too new and the observations too limited to make the conclusion absolute. My object is to stimulate research along this line in other sections of our western mountains. I see in it a powerful check on speculations as to the cause of the past glaciations.

OSCAR H. HERSHEY.

LAS PERLAS MINE,
May 14, 1903.